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SUBJECT: ATM Digital Computer Functions and Backup Capability
Case 620

DATE: December 5, 1968

FROM: W. Levidow

ABSTRACT

The ATM Pointing Control Subsystem currently uses a redundant analog computer and a non-redundant digital computer. This memorandum explores the need for making the digital computer redundant also by describing its functions and its backup capability.

All the functions have a crew manual backup except for Rotation and Distribution Law implementation, Experiment Calibration, Offset Pointing Recording, and Roll Reference Calculation. The Distribution and Rotation Laws are not essential to the mission and the other three would have a backup if the Fine Sensor offset angles and the roll position mechanism angle were made independent of the digital computer.

However, the mission goals may be compromised by the numerous crew tasks required for manual backup. A single crew member task simulation should be held to provide a basis for a decision on a redundant digital computer.

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MEMORANDUM FOR FILE

INTRODUCTION

The ATM Pointing Control Subsystem currently requires the use of a redundant analog control computer (ATMCC) and a non-redundant digital computer (ATMDC). The ATMCC performs functions which are considered vital for mission success, such as implementing the attitude control laws and providing a manual control capability. The ATMDC performs functions which are considered less vital or for which backup is available.

However, concern with the effect of ATMDC failure on the attainment of the mission goals has given rise to the suggestion that the ATMDC also be made redundant. Or further, that the ATMCC be entirely eliminated, its functions being handled by the redundant ATMDC. As an aid to understanding the problem, this memorandum describes the mission functions which currently involve the ATMDC, and defines the backup capability.

The functions will be considered in the order that they might be encountered in orbit, starting at a time corresponding to orbital morning. The telescope axis points to the sun and the cluster x axis lies approximately in the orbital plane as shown in Figure 1. Figure 2 depicts the sequence of functions in a typical orbit. All the functions are executed automatically by the ATMDC, except for the first four which require crew participation.

Figure 3 depicts the crew backup action required in the event of ATMDC failure.

Many of the functions involve data which are displayed to the crew and telemetered to ground. Table 1 below indicates which of the relevant data are and are not dependent on the ATMDC for display and telemetry. This is pertinent to the discussion of the backup capability.

Table 2 presents a summary of the ATMDC functions and the backup now planned. These will be discussed as they occur in a typical orbit.

Table 1

Crew Display and Telemetry

A. ATMDC Dependent

   Fine Sun Sensor Offset Angles
   Roll Position Mechanism Angle
   Roll Reference Angle
   CMG Resultant Momentum H_T

B. Not ATMDC Dependent

   Star Tracker Gimbal Angles
   CMG Gimbal Angles
   CMG Momentum Components H_X, H_Y, H_Z

Table 2

ATMDC Functions	Backup Capability	
Offset Pointing & Recording		No Recording
Experiment Calibration		No
Roll Reference Calculation and RPM Drive		No Calculation
Star Tracker Cluster Occultation	Yes	
Star Tracker Earth Occultation	Yes	
Distribution and Rotation Laws		No
System Timing	Yes	
Day/Night Mode Switching	Yes	
Dump Maneuvers	Yes	
Minimum Momentum Attitude	Yes	

TO SUN

Z

Y

-X

ORBIT

CLUSTER COORDINATES
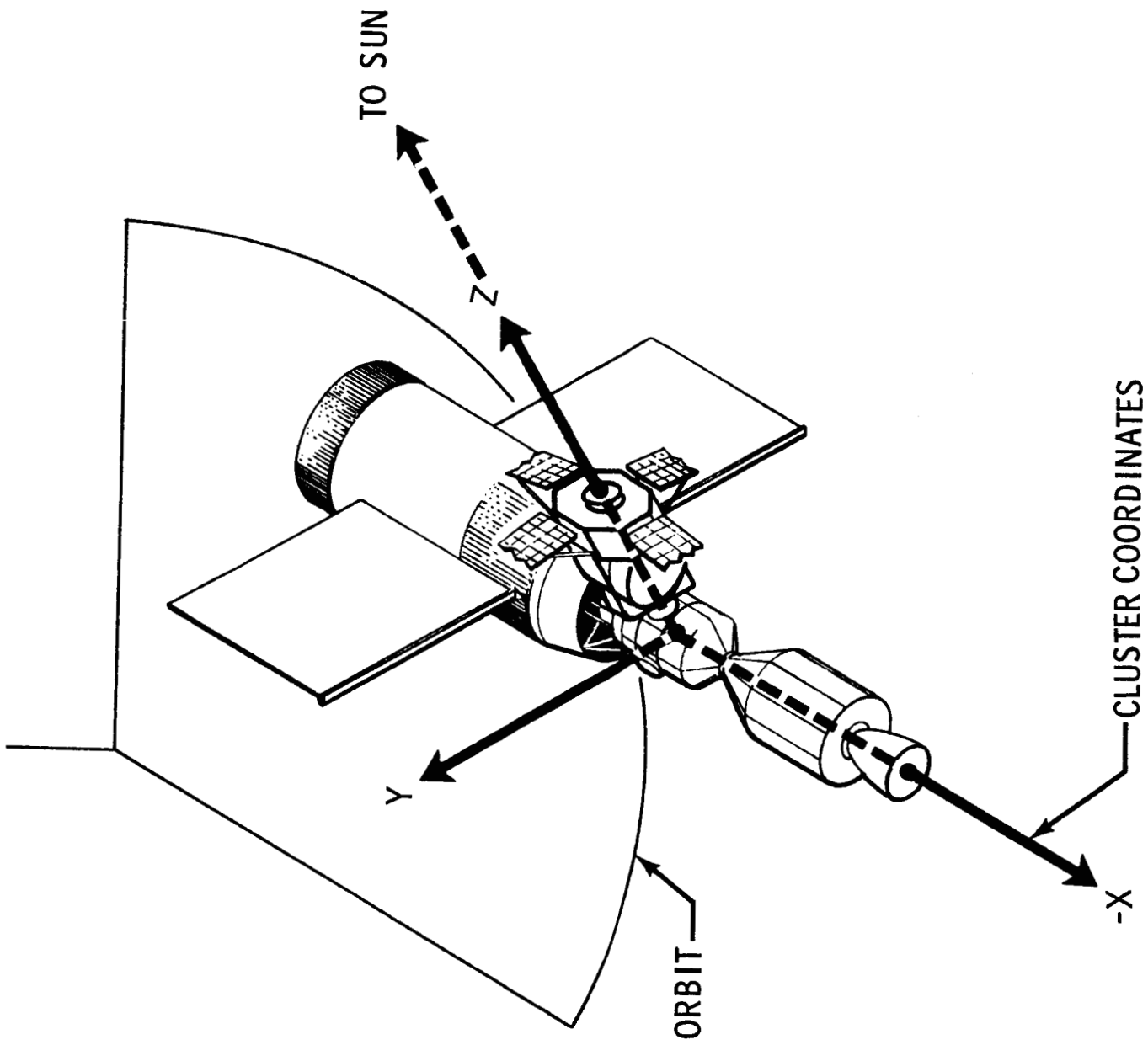
FIGURE 1 - ATM CLUSTER
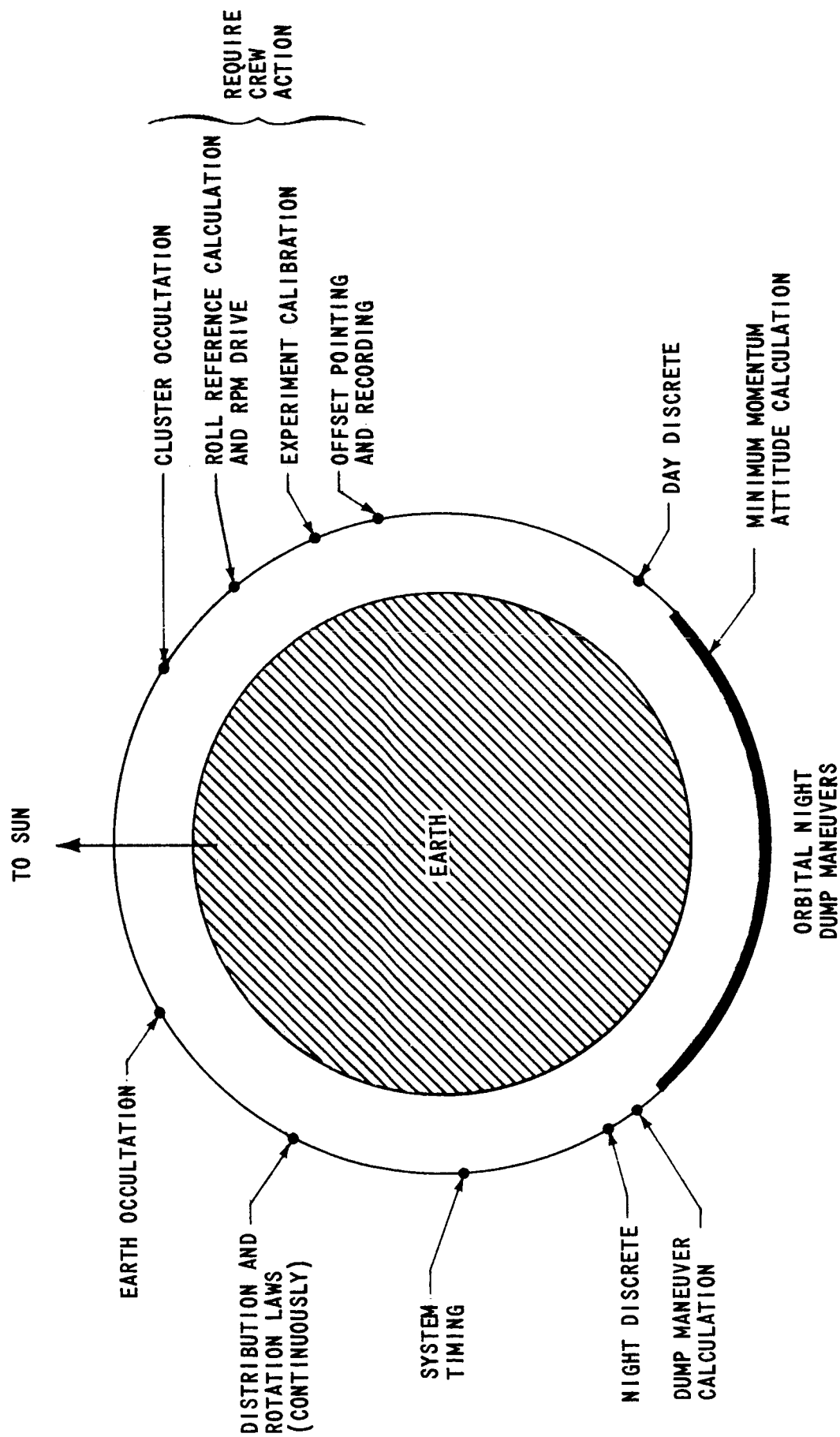
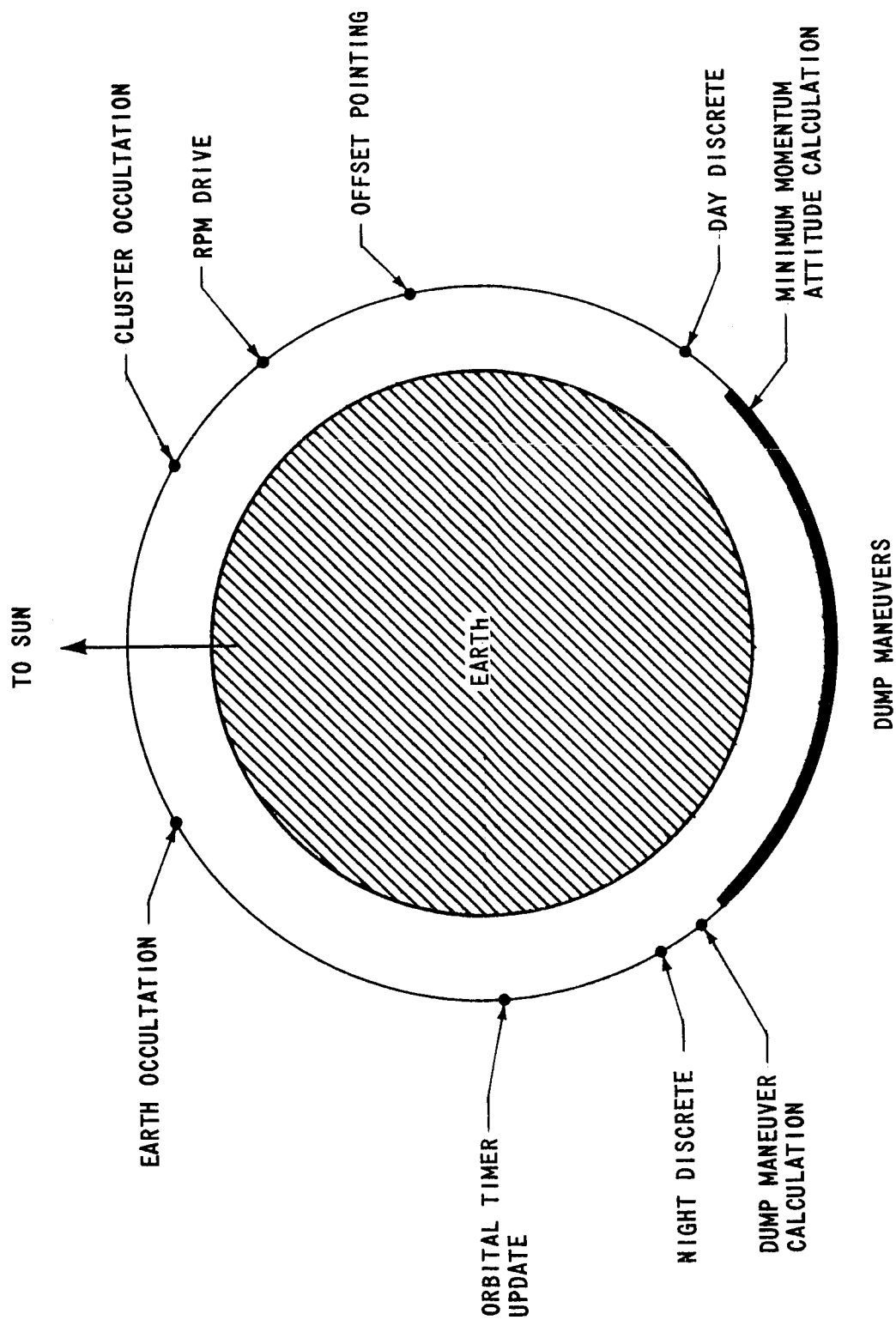FIGURE 2 - FUNCTIONS NORMALLY INVOLVING THE ATMDC

FIGURE 3 - CREW BACKUP ACTION IF THE ATMDC FAILS

OFFSET POINTING AND RECORDING

The experiment telescopes can be pointed off the solar center to any point on the solar disk or to the outer limb. This offset pointing is accomplished by refracting the sunlight by means of optical wedges inserted in the Fine Sun Sensor (FSS) optical system. The wedges can be rotated (offset), producing FSS output x, y error voltages that cause the trim gimbal servo to rotate the experiment package until the error is nulled. As a result, the telescope sight moves through an x, y offset angle from the solar center as shown in Figure 4.

The points of interest on the solar disk may be determined by crew observation of solar phenomena as seen on the TV screen or by a set of coordinates sent from ground. The offset pointing rate is manually commanded by the crew while observing the x and y wedge offset angle readout on the PCS control and display panel. The ATMDC is used for processing the FSS offset angle signal to a form suitable for the crew display, for telemetry, and for recording on the photographic film.

Backup

In the event of an ATMDC failure, the crew can still offset point to areas of interest as seen on the TV screen. However, since the display, recording, and telemetry of the offset angles depend upon the ATMDC, the offset angles are unknown if the computer fails. There is presently no backup for recording the offset pointing angles.

If the crew display or telemetry of the offset angles were made independent of the ATMDC, the angles could be manually recorded and referenced to the corresponding picture frame. It would also enable the crew to reaim the telescope to a previous sight. This manual recording capability should be explored.

EXPERIMENT CALIBRATION

To achieve the pointing accuracy* required of the
NRL/B, the HCO/A, and the Hα #1 experiments it will be necessary
to perform in flight calibrations. This corrects for FSS offset
angle readout errors due to misalignment of the FSS and the line
of sight of each of the experiments. As shown in Figure 5, this
misalignment causes the sight to be displaced from the solar
center by bias angles X_B and Y_B when the offset angles read zero.

The calibration procedure for each experiment requires
the crew to pitch the spar using the manual offset pointing
controller, until the experiment sight coincides with the solar
limb at points X_1 and X_2.** At these positions, the crew commands
a digital computer readout of the corresponding FSS offset angles.
Similarly, yawing the spar provides the digital computer with
limb angles Y_1 and Y_2.

The ATMDC calculates the X and Y bias by:

$$X_B = \frac{X_1 + X_2}{2} \qquad\qquad Y_B = \frac{Y_1 + Y_2}{2}$$

These bias values are then used by the ATMDC to provide corrected
values for recording, crew display, and telemetry.

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* The principal investigators require that the FSS offset
angle readout indicate the experiment sight offset angle to the
following accuracies:

NRL/B	±	2.5	arcsec.
HCO/A	±	10.0	arcsec.
Hα #1	±	5.0	arcsec.

**The details of how this coincidence is determined for
each experiment is given in "Preliminary Apollo Telescope
Mount Digital Computer Functional Requirements Document"
(Revision C), available from the author.

Backup

Since the ATMDC is presently required for knowledge of the offset angles, a calibration backup is not required.

However, if the crew display of offset angles were made independent of the ATMDC, the crew could provide the back-up function by manually recording the limb offset angles X_1, X_2, Y_1, Y_2 and performing the simple bias calculation and correction.
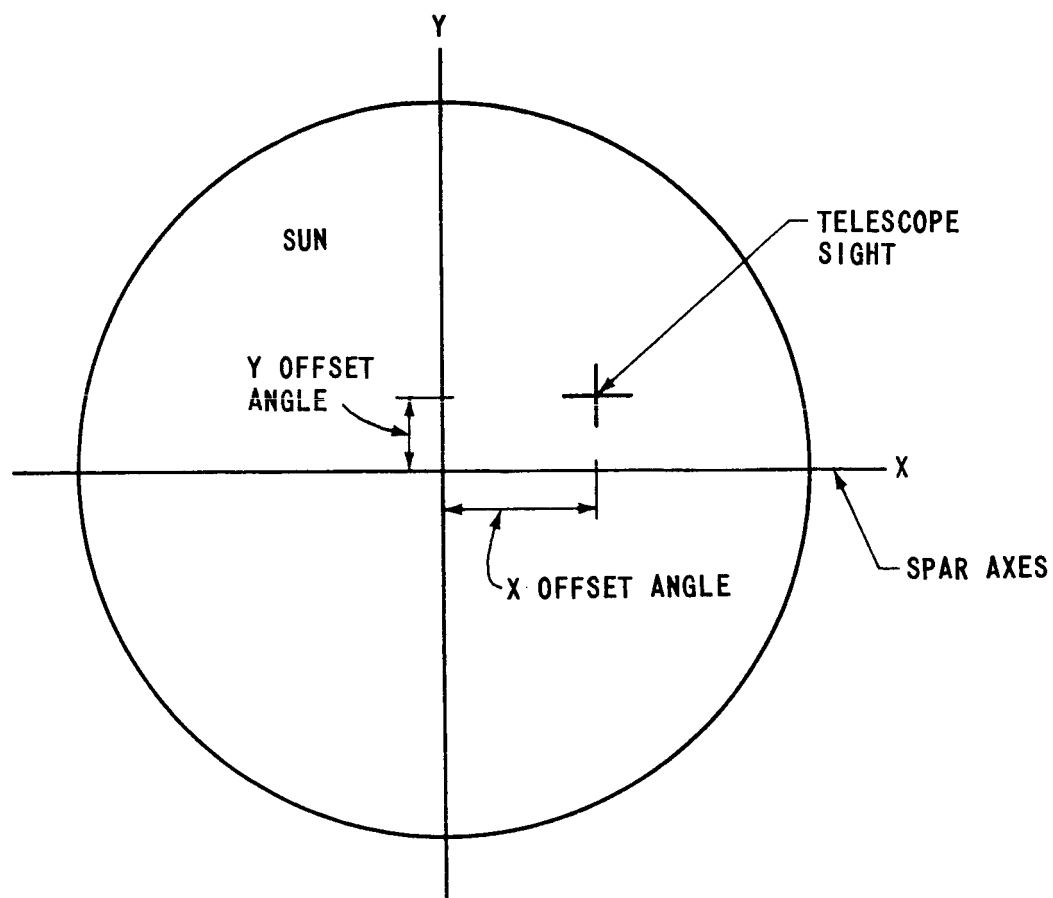
FIGURE 4 - OFFSET POINTING AND RECORDING

FIGURE 5 - EXPERIMENT CALIBRATION

ROLL REFERENCE CALCULATION AND RPM DRIVE

The NRL/B experiment requires the spar Y axis to be rotated about the sun line to various angles (roll reference angle) relative to solar north. This allows the spectrograph slit to be rotated to desired orientations for viewing solar phenomena as shown in Figure 6. The spar Y axis is rotated by crew initiated rate commands to the roll position mechanism (RPM), which rotates the spar about its Z axis relative to the rack.

The ATMDC calculates the roll reference angle from knowledge of the star tracker gimbal angles, which provides the inertial orientation of the rack Y axis, and from the RPM angle, which provides the angle between the rack and the spar Y axes. The roll reference angle is displayed to the crew, telemetered to ground, and recorded on the film.

The ATMDC also processes the analog RPM angle for crew display and telemetry.

Backup

In the event of ATMDC failure, the crew can still roll the spar Y axis to orient the slit on features of interest as seen on the TV screen. However, the roll reference angle will not be calculated, resulting in no knowledge of the orientation of the slit. There is presently no backup for calculating the roll reference angle.

If the crew display and telemetry of the RPM angle were made independent of the ATMDC, this angle as well as the star tracker gimbal angles could be recorded by crew or ground. By referencing these angles to the corresponding picture frame, the roll reference angle could be calculated at a later time. Knowledge of the RPM angle would also allow the crew to orient the slit to a previously determined setting. This manual recording capability should be explored.
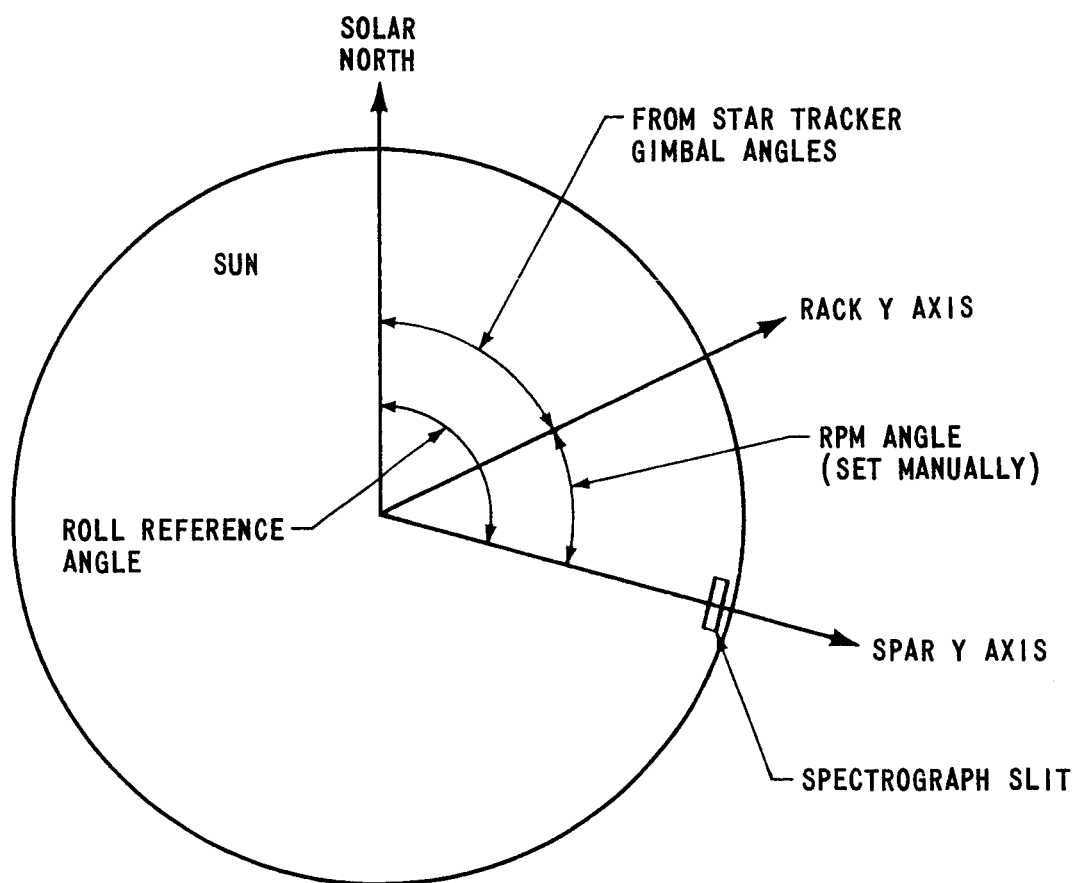
FIGURE 6 - ROLL REFERENCE CALCULATION AND RPM DRIVE

STAR TRACKER CLUSTER OCCULTATION COMPUTATION

Due to the location of the star tracker on the ATM vehicle, it is possible for parts of the vehicle to occasionally obstruct the star line of sight. The primary reference star, Canopus, will be occulted during five separate periods of the year ranging from six to thirty-four days, depending upon launch date. Roll reference determinations to the required accuracy (+10 arcmin.) cannot be attained without a stellar reference. Hence, it will be necessary to occasionally switch the tracker to an alternate star. The function of the ATMDC is to predict and signal the crew that occultation of Canopus by the cluster is imminent.

Prediction of an occultation by the ATMDC is based on the current star tracker inner and outer gimbal angles and knowledge of the combination of gimbal angles which causes the cluster structure to obstruct the tracker line of sight. A signal is sent to the Display and Control Panel which alerts the crew to manually orient the tracker to the alternate star, Achernar. The required gimbal angles for this star are obtained from ground.

By manipulating the manual pointing controller and simultaneously observing the gimbal angles on the display, the crew reorients the star tracker. When the proper angles are attained, the crew commands an automatic search. If the star is within the search field of view, the tracker automatically acquires and tracks the new star.

Backup

Since the ATMDC only predicts and signals an impending occultation, these functions can be performed by ground operations from the telemetered star tracker gimbal angles.

STAR TRACKER EARTH OCCULTATION COMPUTATION

In general, the star tracker line of sight to the primary reference star Canopus will be occulted once per orbit by the earth. The time of occultation will vary with each orbit due to orbital regression and the earth's rotation about the sun. The function of the ATMDC is to predict the time of occurrence of the occultation and issue a discrete which automatically locks the star tracker gimbals and closes its shutter. At the end of the occultation period, a second discrete from the ATMDC automatically commands reacquisition of the star.

Backup

From knowledge of orbital parameters, ground can predict the time of occultation and advise the crew. The crew can issue the required discrete commands via the ATMCC.

DISTRIBUTION AND ROTATION LAWS

Although the CMG control law commands the magnitude and direction of the total CMG angular momentum vector, the direction of the individual CMG gyro spin axes are not uniquely defined. The function of the ATMDC is to implement the Distribution and Rotation laws which prevent the three spin axes from assuming an undesirable orientation. Gyro gimbal rate commands generated by the ATMDC are continually superimposed on the normal gimbal commands required for attitude control.

The Distribution Law is designed to orient the three spin axes, without affecting the resultant momentum, such that they are arranged symmetrically about the resultant. That is, they make equal angles with the resultant and equal angles with each other.

The Rotation Law is designed to rotate the three gyro spin axes about the resultant such as to minimize the gyro inner gimbal angles. This prevents an inner gimbal from hitting its +80° stop, for if a gyro hits both its inner and outer gimbal stops, its usefulness may be temporarily lost. Although CMG control can be exercised with only two active gyros, control is lost if two gyros are hung up on their stops.

Backup

Although there is no backup, the execution of these laws is not vital to the mission. RCS thruster torque can be applied to drive the spin axes out of any undesirable orientation.

SYSTEM TIMING

The ATMDC function of system timing is that of keeping an accurate account of time into the mission, of displaying to the crew the remaining time intervals of useful day and night, and of determining the proper time to issue discretes such as the night/day discretes, earth occultation discretes, and dump maneuver commands. This requires the ATMDC to keep track of the vehicle's position in orbit by periodic update from ground.

Backup

In the event of ATMDC failure, ground can perform the timing calculations and communicate the required information to the crew. MSFC has proposed that the crew be provided with a Portable Orbital Timer which would be manually updated once per orbit by instructions from ground. The clock has sliding indicators which can be set manually to correspond to times at which crew action is required. An alarm can be set to indicate at these times.

DAY/NIGHT MODE SWITCHING

Automatic switching of the ATM Pointing Control System from day to night operation and back again to day is initiated by the timekeeping discretes from the ATMDC. This mode switching must be performed well within the sunlight portion of the orbit to prevent the distorting effect of the atmosphere on the sunlight from imposing transients on the control systems.

Night Discrete

Prior to sunset, the ATMDC issues discretes which:

(1)   Transfers CMG vehicle attitude error control from the acquisition sun sensors to the integrated output of the rack mounted rate sensors.

(2)   Inhibits the Experiment Pointing and Control System and locks the spar gimbals.

(3)   Inhibits the star tracker (locks its gimbals and closes its shutter) in preparation for dump maneuvers.

Day Discrete

Upon entering daylight, the ATMDC issues discretes which:

(1)   Transfers CMG vehicle attitude error control back to the acquisition sun sensor.

(2)   Commands the star tracker to search for the reference star.

The crew must manually switch to the Experiment Pointing Mode to reactivate the Experiment Pointing and Control System.

Backup

The night and day discretes can be issued manually by the crew from ground instructions.

DUMP MANEUVERS

During normal operation, with the ATM cluster oriented to point at the sun, bias gravity-gradient and aerodynamic torques act on the cluster and cause CMG momentum accumulation. This momentum is dumped during orbital darkness by reorienting the vehicle such that gravity-gradient torques act to cancel the accumulated momentum. The function of the ATMDC is to determine the magnitude of the momentum to be dumped on each axis, to calculate the required dump maneuvers, and to issue maneuver commands to the vehicle.

The ATMDC samples the absolute magnitude of the CMG angular momentum vector $\underline{H}_N$ during the Nth orbital daylight period. The minimum and maximum values are retained and the average $\underline{Hm}_N$ calculated. The momentum to be dumped during the Nth orbital night interval is determined by:

$$\underline{H}_{D_N} = \underline{H}_{D_{N-1}} + K_1 (\underline{Hm}_N - \underline{Hm}_{N-1}) + K_2 (\underline{Hm}_N - \underline{H}_O)$$

The first term on the right is the amount dumped during the previous orbital night. The second term is the increment to be dumped due to the difference in the accumulated momentum between the Nth orbital daylight period and the previous one. The third term causes the average momentum to converge to a preselected value H_O. H_O can be chosen such that at maneuver time the gyro spin axes are aligned in a favorable direction for making the maneuver.

The dump maneuvers are calculated by operating on $\underline{H}_{D_N}$ with a matrix Γ which is a function of CMG gimbal angles and orbital time.

$$\underline{e} = \begin{bmatrix} 0 \\ e_y \\ e_z \end{bmatrix} = \Gamma \underline{H}_{D_N}$$

This results in small dump maneuver angles e_y and e_z about the vehicle Y and Z axes. An X axis maneuver is not made because large maneuvers about this axis are required for significant dumping action. The currently proposed Γ matrix results in a three-maneuver, two-axis dump procedure, $\underline{e}$ being held at one value prior to midnight and generally a different value after midnight. The ATMDC commands the vehicle to the dumping attitudes by signals to the ATMCC.

Backup

     With ATMDC failure, the crew is obliged to manually command the required dump maneuvers. By monitoring the absolute values of momentum along each axis at a fixed point in each orbit, the per orbit momentum accumulation can be determined by the crew or ground. The major part of the accumulation is due to gravity-gradient and lies along the X axis. To minimize crew preoccupation with dumping, this X axis momentum can be dumped by a single large X axis maneuver after sunset and a reverse maneuver before sunrise back to the pointing attitude.* The proper maneuver angle and maneuver time can be determined by the crew from charts or from instructions from ground. When the angle between the earth-sun line and the orbital plane is less than 30°, the entire daylight accumulation of momentum produced by gravity-gradient torque can be dumped by this method during orbital darkness. For angles greater than 30°, reaction thrust dumping is also required. Occasionally ground will advise a Y and Z axis maneuver to dump the momentum accumulated on these axes.

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     *W. Levidow, "A single Axis, Two Maneuver Gravity-Gradient Dump Procedure for AAP-ATM Missions", Bellcomm Technical Memorandum TM-68-1022-4, September 20, 1968.

MINIMUM MOMENTUM ATTITUDE CALCULATION

To minimize the CMG angular momentum buildup along the Y and Z axes, the cluster X geometric axis should in general be oriented a small angle out of the orbital plane. There are two contributing factors:

(1) The Y and Z axes bias torque due to gravity-gradient is zero if the X principal axis lies in the orbital plane. However, the principal and geometrical axes do not coincide.

(2) Aerodynamic force produces a Y and Z bias torque. By rotating the X principal axis out of the orbital plane a gravity-gradient torque is developed which counteracts this bias torque.

Hence there is an optimal angle between the cluster X geometric axis and the orbital plane such that the Y and Z axes momentum accumulation is a minimum.

The function of the ATMDC is to calculate this optimal angle on a per orbit basis and to command the desired vehicle rotation about the earth-sun line. The calculation is based on a momentum sampling method* similar to that used for calculating dump maneuvers.

Backup

The momentum sampling and attitude correction calculation can be performed by ground and relayed to the crew. This correction can be manually commanded by the crew.

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*It may be necessary to initially align the vehicle X axis with the orbital plane using the CSM attitude reference system or possibly the ATM Star Tracker. Note that the primary function of the Star Tracker is now that of determining the Roll Reference Angle, not the location of the orbital plane.

SUMMARY

      As shown in Table 2, all functions have a manual backup, except offset pointing recording, experiment calibration, roll reference calculation, and Distribution and Rotation law implementation. All but the last of these would have a manual backup capability if the crew display or telemetry of the offset angles and the roll position mechanism angle were made independent of the ATMDC. This capability should be explored.

      However, even with this added backup capability, Figure 2 indicates that the mission goals may be compromised by the numerous crew tasks resulting from ATMDC failure. A preliminary simulation at MSFC indicates that these tasks can be handled by two crew members. But with the possibility of failures in other systems as well, the undivided attention to the Pointing Control System of two crew members may not be available. A single crew member simulation of these tasks should be held in the future. The results of this simulation will help provide a basis for a decision on a redundant ATMDC.

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